AUTOMATIC ELECTRICAL TESTING IN MECHANIZED PRODUCTION LINES

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PREFACE

Quality control of automatic, mechanized production lines is based upon automatic testing techniques. This paper outlines the testing requirements for such a production line and proposes methods for accomplishing these requirements. The ideas and methods promulgated were conceived during the industrial tour of duty assigned as an integral part of the Engineering Electronics Curriculum of the U. S. Naval Postgraduate School.

Acknowledgment and appreciation is hereby extended to Stanford Research Institute, Stanford, California, where the industrial duty was performed, for their suggestions and the opportunity to develop the theories contained herein.

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I. INTRODUCTION

It has been said that the enormous production capability of United States industry was a major factor in the allied victory in World War II. There seems to be considerable evidence to support this statement. Not only did industry supply large amounts of ordnance and equipment with relatively short notice, but also it proved to be readily adaptable to the production of new types of weapons and military supplies in sufficient quantities to allow the allied forces to carry the war to the enemy with the utmost strength.

Probably mass production techniques, developed over a period of many years for peacetime applications, attain the highest degree of importance among the many factors contributing to this production capability. Certainly the sound engineering principles which underlie these techniques are indispensable to the industrial effort of many manufacturing concerns striving cooperatively toward the common goal of optimum production.

There is doubt, however, that the production effort and techniques used during World War II, as heroic as they were, would be sufficient to meet the needs of a third and even more highly technical full-scale war. The increase in quantities required and the

addition of many new types of expendable electronic equipment, for example, would impose a severe tax on the industrial facilities known during the period from 1939 through 1945. These engineering principles, therefore, are being applied in a large effort being directed to the development of new means and techniques of mass production which will enable American industry to meet these heavier demands.

A resulting trend of this development has been toward more automatic production than has been evidenced in the past. While the morale of the working man, and thus his production rate and efficiency, was exceedingly high during World War II and contributed greatly to the overall production picture, it is still felt that elimination of the human link in a production chain will allow a considerable increase in the output of such a chain, not only in quantity per se, but quantity in the sense of fewer items rejected due to inferior quality. This theory then justifies this trend and the amount of effort being dedicated to the development of automatic, mechanized production lines which will fabricate end products from raw materials, will be self-controlling and self-supplying of components, and will include means for applying periodic tests to the product being fabricated to insure uniform high quality in the finished items. This endeavor has already resulted in a considerable amount of mechanization

of industries. While overall assembly lines are still found wanting in complete automaticity, many components and individual processes are being handled automatically in the course of production.

Quality control by automatic testing at significant points in a production line is somewhat lagging the basic processes as far as development is concerned, but it is receiving an increasing amount of attention at the present time. Several electronic component manufacturers, such as International Resistor Co. and Centralab, are using semi-automatic methods for testing their products before crating and shipping. These methods usually entail hand-feeding the component to the machine, which then tests the component and routes it to various receivers on the basis of the tolerance values determined by the test. Versatility features, however, again are referred to the human being. If a different value component is to be tested, the machine is changed manually to accommodate the new value. This still allows increased production and indicates the possibilities of completely automatic testing.

An automatic assembly line for the fabrication of miniaturized electronic equipment is under development at Stanford Research Institute, Stanford, California, under sponsorship of the United States Air Force. In essence, it will receive materials

and commercially available electronic components and assemble them into a single piece of equipment by a continuous process from beginning to end, without human assistance, other than preliminary supply functions. The intent of this paper is to propose the logical electrical tests to be performed on the assembly during its fabrication and to indicate various methods by which these tests can be accomplished.

II. TESTING REQUIREMENTS FOR AUTOMATIC ASSEMBLY LINE

In a truly automatic, mechanized assembly line for electronic equipment, it is desired that all functions, except initial loading of component materials, be completely automatic and the process be one of continuous flow from the insertion of these materials to the removal of the final product, wrapped and crated for shipping. As an added requirement, it follows naturally that this assembly line must be capable of a high production rate in order to make economically feasible its adoption in preference to present hand production methods.

These stipulations pose several interesting problems. Not only must assembling and processing machines capable of performing the various functions at reasonably high rates of speed be designed, but also provisions for automatic control of these machines be made. There must be some assurance that the product being assembled is correct in performance before it ever leaves the line. As a quality control measure, then, provisions must be made for automatic electrical testing of the assembly before it leaves the line. Further, economy considerations require that faults in the processing be detected at various stages during assembly in order to prevent waste of components or further processing on a chassis which might be defective at some earlier stage.

There are several general, basic requirements common to testers for any of these stages of assembly. These are:

1) Versatility -- It is contemplated that the assembly line shall be capable of producing different types of equipment by a change of tooling and components. Similarly, the testing equipment must be adaptable to the various possible circuits and physical configurations which might be fabricated by the production line. This implies a programming feature for each tester which would allow the change while other tooling is being substituted.

2) Positive Judgment -- Testing equipment must allow an assembly to pass, on a tolerance basis, or it must cause it to be rejected, if the assembly does not meet the required specifications.

3) Reliability -- Rejects due to test equipment errors must not be tolerated.

4) Recording -- For statistical quality control, a continuous recording of fault indication must be made to allow process error evaluation.

5) Process Control -- Means should be incorporated into the testing equipment for sounding an alarm, or possibly even shutting down the production line, in the event of excessive reject rates from one particular stage of fabrication.

6) Error Indication -- In some cases it might be desirable for the test equipment to mark the rejected piece with a code number to locate the fault for simple and rapid reclamation of the piece.

Specific testing requirements can be determined after it has been decided what processes shall be included in the production line and in what order they shall appear. A block diagram of the Stanford Research Institute production line under development appears in Figure 1. While other interests have undertaken similar projects, with somewhat different techniques, it is felt that this particular assembly line will serve as an example for the determination of testing needs. Referring to Figure 1, it appears that the following constitute a logical and complete testing system:

1) A tester inserted after the etching equipment to test the printed conductor pattern for the efficacy of the etching process;

2) A tester inserted before the R-C component feed system to check components;

3) A tester inserted before the protective coating applicator to check the existing circuit; and

4) A tester inserted before the packaging machine to test the performance of the completed assembly.

Justification for the above selections results from the following considerations:

1) Etching processes in production quantities, as separate from laboratory conditions, can and do pose serious problems. While some processes give excellent results in the laboratory, production-line equipment falls short of these results. The photo-etching process, for example, is one of the better methods for producing high-resolution, finely detailed printed circuits. North American Aviation, Inc., however, has had as high as forty per cent rejects from a given run through their equipment, resulting from factors which are difficult to control in production-line equipment, such as dust and vibration. The method contemplated by Stanford Research Institute was developed at and patented by the Institute, and still falls short of the ideal system. In brief, the printed conductor pattern is produced by spraying a mixture of wax etch resist and a non-corrosive solder flux through a steel stencil onto the laminated base plate. This steel stencil is held tightly to the base plate by means of a large electromagnet, whose field is directed through the plate. The plate is then subjected to a spray of nitric acid, which removes all the undesired copper. Figure 2 shows the conductor pattern after it comes from the etching bath. Examination of this drawing will show that some parts of the stencil are held together only by very thin strips of the metal of the stencil itself. This alone, by virtue of resist mixture leaking under

the stencil, can give rise to two faults -- either a shortening of the distance between two conductors at their close spots, with its resultant tendency to arc over, or absolute short-circuiting of the two conductors. Inaccuracies in the previous laminating process result in bubbles, or even breaks in the copper, which interrupt the continuity along one line. Thus, there seems sufficient justification for a tester at this point to check continuity, bridging and clearance.

2) Other than noted in Chapter I, components normally commercially available are unchecked for tolerance compliance other than by normal quality control methods by the manufacturers. Since there are circuits whose performances are sufficiently critical to be non-operative with a single defective component, this test of component values is justified.

3) Due to the number of operations performed on the circuit up to the application of protective coating, including much physical machine handling and also the heat of the dip soldering equipment, and to the difficulty in reclaiming a piece after the coating has been applied, it is advisable to perform some sort of a circuit test at this point to insure that no damage to the piece has occurred.

4) The ultimate measure of the acceptability of the finished product is, of course, its performance. Purchasers of a product are unlikely to be satisfied with it, no matter how it was assembled,

if it doesn't perform its designated function correctly. Therefore each assembly should be checked before leaving the production line.

While the results of the above discussion appear obvious, and such tests are performed in existing production lines on a sampling basis, it must be borne in mind that all these functions must be performed automatically, on every assembly, and, at the same time, at a rate commensurate with the rest of the process, so that the testers will neither hold up the line behind, nor jam up the line ahead. Means for accomplishing these tests automatically will be discussed in Chapter III.

III. AUTOMATIC TESTING METHODS

In the preceding chapter, the basic electrical testing requirements for an automatic production line were discussed. The stages of production for insertion of the testers were selected and the functions of the testers at each spot were enumerated. This chapter will describe the methods for accomplishing the proposed tests.

In general, automatic testing proposes no new basic principles of testing. It does, however, present problems which, while in some cases have been solved in other applications, are peculiar to this particular field. Mechanical engineering plays an important role in the automatizing of any process, specifically in the functions of feeding, connecting, and removing of the work piece to, in, and from each of the various stages. This is true also in automatic testing. Problems arise in electrical engineering, however, such as commutation, or switching, of the various circuits to be tested by one machine, reject, recording and alarm circuits, and types of comparison or absolute-value testing circuits. Some of these problems have been solved, and their solutions can be found in the literature, part of which is listed in the bibliography appended to the paper, but there are others which are worthy of further consideration. The program of presentation in this chapter will be to propose one or more methods of meeting each of

the requirements of the system, with pertinent comparisons made. Where specific application is necessary, the test vehicle used for development purposes by the Stanford Research Institute will be used to such ends. This test vehicle is the error signal amplifier and automatic gain control section of a current gun-directing radar.

1. Tester #1 - Etched conductor pattern.

As stated above, this tester will check continuity, line bridging and line clearance. If a fault occurs, the tester will reject the piece, record the fault information and possibly stamp the piece with this same fault information for purposes of reclamation. If a number, say "N", successive assemblies are rejected, the tester will cause an alarm circuit to be actuated. Figures 3 and 4 are block diagrams indicating the functions of the tester. Figure 3 shows the physical, or mechanical layout of the tester, while Figure 4 indicates the electrical elements and their interrelation.

a. Basic Electrical Theory for Tests.

Figure 5 shows the basic theoretical circuits for the various tests to be performed. Power supply is shown as a battery for simplicity's sake only -- the detailed design of the power supply depends on the requirements of the actuating relays used in the system.

(1) Continuity.

The continuity checking circuit is attached in such a manner that its associated relay operates unless its coil is relieved of its current by a short circuit across its terminals. This short circuit is accomplished during testing by the continuity of the etched conductors. Since there is a multiplicity of conductors, there arises a problem during the switching from one conductor to the next. Unless some method is devised for maintaining this short circuit, the relay will operate, giving false information. If a mechanical commutator is used for the switching, this can be accomplished by: (a) providing shorting segments on the commutator which will be spaced in from the normal segments, between and overlapping them slightly, (b) providing an interrupted power supply, such as a square-wave generator, or cam-operated switch synchronized with the commutator, or (c) attaching the relay leads to each segment, thus applying voltage only during such times as the conductors are connected for test. Of the above three possibilities, the second is probably the best method to use. The first method calls for a more complex and expensive commutator, with higher brush maintenance and more weight. The third would result in a maze of wires to occupy a space already taken up by leads to the probe assembly, as will be seen later in considerations of mechanical commutators. In the second method, a square-wave generator would

require more complex circuitry, and both interruption methods would require careful synchronization. However, these problems are minor in comparison to those noted for the other methods.

(2) Bridging and Line Clearance.

These tests are identical, except for the magnitude of the applied voltage, so they can be explained in the same manner. The circuits are designed so that the associated relays operate only if there is a short circuit occurring at the probes, which would be the case if there were bridging or arc-over in the circuits. No intersegment difficulties are encountered in these tests, since the short circuit in this case is a fault to be detected.

It is contemplated that the reject circuit would be a preparatory circuit, that actual rejecting of the piece would not occur until the entire testing has been completed.

A problem which merits attention is the possibility of such a line configuration which would allow bridging between one portion of a conductor and another portion of the same conductor. With the circuits as they are, there is no way of detecting this type of fault. Probably the only way of detecting it is visually. It is felt, however, that this particular type of configuration would not occur often, nor would it affect the performance of the circuit, so no particular precautions are necessary. Other

combinations of faults may occur, but at least one of the three tests would be able to detect the error.

b. Electrical tester to pattern contact.

With the basic theory as stated, there is the question of making electrical contact between the test circuit and the conductor pattern. This can be accomplished through a set of probes, against which the pattern is forced when the base plate enters the testing machine. Since the machine designs indicate that a single size base plate will be used for all the different assemblies which the production line may be called upon to fabricate, the problem of versatility is then one of locating these probes to make contact with the terminations of the conductors. This can be done in two general ways, either a grid-type arrangement, or a rigid template.

(1) Universal Grid

(a) Fixed Probe.

The head which contains the probes could be made up of a plate of insulating material, marked off into squares, with a probe located in each square. Thus, when the head is pushed together with the conductor pattern, certain of the probes would be located on the terminal points of the conductors. These probes would then be connected to the commutating system and thence to the test circuits. Such a scheme could possibly be programmed by push-button type machines, but would involve complex and expensive equipment.

Manual connection of the probes to the distribution system would be indicated instead.

(b) Perforated Grid, Movable Probe.

A modification of the above scheme is to have the grid, but with probes which can be removed when they are not in use. This may be better in the case of high voltage testing. Either method is versatile, but both require that the conductor pattern be designed in conformance with the grid in order to insure the meeting of all terminations with one probe.

(2) Template Arrangement.

Another method for overcoming the obstacle mentioned above is one in which a template is prepared for each pattern to be tested. Such a template could be formed using the resist-applying stencil as a pattern with a casting material as a forming medium. This would be rigid and insulating and would allow exact placement of the probes. This system sacrifices versatility, since the template can be used for that particular pattern alone. Its solution to the lay-out problem, however, probably makes it the better scheme to use.

c. Channel multiplicity considerations.

With electrical contact to the individual conductors assured, some attention must now be given to the means for completing the test circuit with all the conductors on the base plate.

Let the word "channel" denote the inter-connection of two probes and the intermediate means for attaching the testing circuit. In that sense, then, the system whose conductor pattern is shown in Figure 2 represents the following requirements:

No. of lines	No. of terminals
43 Two-terminal	86
21 Three-terminal	63
1 Four-terminal	4
1 Five-terminal	5
Totals 66 lines	158 terminals

In order to provide a complete check of continuity on the above, a total of 92 channels is required. This arises from the fact that each n-terminal line requires n-1 channels. There are approximately 35 possibilities for bridging or line clearance errors.

There are essentially two methods for including all these channels in the testing -- to accomplish the testing of them simultaneously, or, with appropriate switching, to do them consecutively until all have been tested.

(1) Simultaneous testing.

In order to perform one of the tests on all the conductors simultaneously, it is necessary to have a single power supply and the associated control-circuit relays for each channel, with a master switch to turn on the system and to switch from one

test to the next until all three tests have been applied to the conductor pattern. This appears to be the most simple means of testing the pattern, with no complex switching arrangements and with little or no difficulty in meeting stringent time requirements. However, it does require a large number of relays and power supplies, and the resulting size of such a system might make it prohibitive in its final form. The initial adjustment and continuing maintenance of the system also contribute to the undesirability of the system.

(2) Consecutive testing.

While more complex in nature, a system for testing each conductor consecutively might prove to be simpler in form than one for simultaneous testing. In general, such a system would incorporate a single testing circuit for each of the three tests and a mechanism for switching from one conductor to the next until all are tested. Let us, then, look into the requirements of such a system.

(a) Time considerations.

The plans for the overall production line call for a production rate of ten per minute, or one every six seconds. Since the tester must neither retard nor jam the entire process, it should be designed with time considerations compatible with the rest of the assembly line. Allowing sufficient time for the feed and removal

of the base plate from the tester, say on the order of three seconds for both actions, there remain three seconds for performing the testing. On the basis of 100 channels, then, the commutator must complete an entire cycle in three seconds, or twenty cycles per minute. This allows an absolute maximum time of three hundredths of a second for completion of the continuity checking of one conductor. Somewhat less time is allowed for each conductor if mechanical commutation, or stepping relay switching is used, due to the inoperative interval required between each channel.

(b) Commutation Systems.

Preliminary studies indicate that any one of three types of commutation may be used -- mechanical, electro-mechanical, or pure electronic. Any of these systems might be adapted to fit the needs of the tester. It is feasible that all three tests may be performed simultaneously, the limiting requirement being that complete isolation among the tests be maintained.

(i) Mechanical System.

Rotating commutators have been used in numerous applications for many years. They are generally long-life, low-maintenance systems, but have limitations as to maximum number of channels, speed and ready changeability. In this application, it would be necessary to have two contacts for each channel in order

to meet isolation requirements which result from the simultaneous testing. The physical form suggested for the testing application is as follows: Install channel segment pairs symmetrically around a circular ring stator, there being one stator for each testing function, and apply the testing signals through brushes located toward the outer end of an arm which rotates on a shaft common to the axes of the three stators. See Figures 6 and 7. This scheme simplifies the channel isolation problem and precludes the necessity for any other synchronization among the testing functions. A problem exists, however, in the high voltage testing due to stringent insulation requirements in the commutator itself. This could be solved by adding relays to the system. See (ii) below. The mechanical system has another advantage in that other parts of the system, such as the fault indication mechanism and the quality control recording mechanism, can be geared directly to the rotor of the commutator, thus exactly synchronizing the detecting and recording functions. This will be discussed later in connection with fault indication.

(ii) Electromechanical Switches.

A system could be devised whereby commutation of the channels would be accomplished by stepping relay switching such as used in telephone systems. This would require synchronizing, or "lock-out" switches to accomplish circuit isolation. A combination of this with (i) above can be formed by using the

rotating machinery as a camshaft, with cam operated relays. This might be especially advantageous for high voltage testing. It would also incorporate the inherent synchronization features of the mechanical type. The main difficulties arising with the use of relays stem from the time requirements for the testing. Cost of relays which will operate this rapidly and maintain their speed after many operations might prove to be prohibitive.

(iii) Electronic Means.

Ring counters and other multivibrator circuits have been developed for various switching and triggering applications and could be adapted for this purpose. It is felt, however, that these would be quite complex circuits for such a large number of switching operations, which, coupled with the general unreliability of systems using vacuum tubes in on-off operation, would be unfavorable in comparison to the other systems.

In order to overcome this reliability problem, a diode-resistance matrix such as shown in Figure 8, employing germanium diodes, could be used. The main disadvantage of this circuit would be the almost prohibitive number of diodes required to accomplish switching of the large number of test circuits.

d. Fault Indication and Recording.

It has been proposed, for the purpose of reclaiming a rejected piece, that provisions be made for stamping a mark on the

base plate which will identify the conductor or conductor pair which has caused the reject. This may not be completely desirable from an economic standpoint, but methods for achieving it will be described. Extension of the same methods can be used for continuous recording for statistical purposes.

There are two general methods of approach to this problem. The first is to consider a mechanism which will stamp each reject identification as it occurs during the testing. The second is to consider a data storage device which would store the information until after the testing has been completed and the piece rejected into a stamping chamber.

(1) Stamping during testing.

The slow operating speed of presently available geared indexing mechanisms prevents their use for this purpose. It appears necessary and feasible, then, to employ a coding system to identify each conductor which is faulty. A seven-digit binary code will allow 128 different code combinations, 96 of which are shown in Table I. This particular number was chosen, since it meets the needs of the system, and allows the maximum possible symmetry of coding. It is contemplated that a repairman would have a master code for comparison and identification purposes.

The mechanical means for stamping the base plate present another problem. Due to lack of available space on the

face of the base plate, it would be advisable to stamp the reverse side. Also, the base plate is of a relatively hard material. A stamp sufficiently forceful to indent the base material could possibly fracture the material. Therefore, an inking or carbon ribbon system is suggested. The synchronization of the stamp in accordance with the particular commutation segments providing the testing signals can be accomplished by a cam system geared to the commutator. The cams could then operate plungers directly and continuously with the reject signal causing the entire housing to move against the base plate. Or, the cams could prepare solenoid plungers which would actuate only on closure of the stamping circuit by a relay which receives the reject signal. The mechanism should then be translated a short distance in order to prevent superposition of two stamps. Limitations on this system occur due to the necessary time for solenoids and relays to act. They must be sufficiently rapid to actuate during the segment travel time allowed, or on the order of two one-hundredths of a second. There is also the unfavorability of the repair technician having to decode the indication. Figure 9 shows the length of make and relative phasing of the cams for 96 channels.

(2) Data Storage System.

In order to overcome the difficulties mentioned above, the fault identifications could be stored in a device until the

testing is completed and the piece rejected into the stamping mechanism on its way to the reject bin. Then the stamping mechanism would receive the marking signals from the storage device at a rate which would allow use of number indexing mechanisms. An arbitrary limit would be placed on the number of faults stamped, on the basis that any number over this limit would make the piece completely irreclaimable.

The storage device could be a punch-card, one for each base plate. The punching would be on a coded basis, using the coding principle of the preceding section. After the reject has occurred, the card would be passed to the stamping mechanism for decoding of the card and stamping of the piece, and thence to a file for permanent record. This would eliminate the need for another separate recording device. In the case of simultaneous testing, either of the above methods could be used, with slight changes. For stamping while testing, each circuit would contain its own coding device for stamping, instead of the synchronized cam arrangement. The same would be true of a storage system. The provisions for this coding also add to the physical complexity of the simultaneous system.

(3) Permanent Recording.

In the event that the system described in the preceding paragraph is not used, continuous recording can be accomplished by

punching a moving tape, as in teletype systems, or by burning with an arc as in facsimile systems. The latter would probably be faster and have longer life in general.

e. Alarm or Shut-down.

It is desirable, for economic and quality control reasons, that a number of consecutive rejects should cause an alarm signal, or possibly even a complete shutdown of the processing equipment.

The method for providing an alarm signal can be purely electronic, such as a ring counter with the last stage closing the signal circuit. Or it can be a relay lock-up counter as shown in Figure 10. In this circuit, the switching of S_1 from one throw to the other causes the progressive lock-up of the relays. S_1 must be a special relay or a separate relay circuit in which the first reject signal operates it to position 1. The next signal then causes it to operate to position 2. Successive reject signals continue this alternation until the counter has completed its cycle. If a switch such as this is not available, or too complex, the substitution of a normal single-pole, single-throw relay can be made by doubling the number of relays in the counter. Then two relays lock up for each count. The counter is reset automatically when the power supply to the line is interrupted. Therefore, if the chain of rejects is interrupted by passing an acceptable base plate, the passing mechanism would be arranged to operate the reset circuit breaker, a normally closed switch.

f. Alternative Testing Method.

An alternative testing method which might be considered under certain circumstances employs the use of photoelectric cells. While not performing an actual electrical test of the elements on the base plate, it does simulate a close visual inspection by a human monitor. This accomplishes all three tests at once and eliminates the probe system and high voltage difficulties mentioned. In brief, the system would call for simultaneous scanning, by adaptation of any of the various high-speed facsimile scanning methods, of the test plate and a good model plate. The outputs of the two scanners would be fed, then, to a differential comparator circuit, whose output is dependent on the difference between the signals from the two scanners. Sufficient resolution could be obtained in the scanning to detect bridging, line clearance, or continuity errors. Error indication would then be transmitted as a coordinate position on the base plate.

The principal limitation on such a system would lie in the difference in reflection coefficients of the conductor and the base plate materials. This difference must be sufficient to give a positive indication of passing from one material to the other in scanning across the plate. Also the error indication

equipment could possibly give rise to undesired complexity in the translating of the time of an error occurrence into a corresponding coordinate position on the base plate and thence into the particular conductor involved.

This method is not considered as a great improvement over the others, mainly due to the fact that an actual electrical test is not performed. Without the error indicating equipment, however, it might prove to be less complex, and completely universal in its application, and for that reason has been mentioned here. For further study of the details of such a tester, the reader is referred to any of the writings on facsimile systems.

2. Tester #2 - R-C Components

The actual testing of the R-C components does not occur directly in the production line, but as part of a feeder line. From that aspect, it could be eliminated from consideration here, but since it is considered to be a necessary adjunct to the system as a whole, the essentials of the system will be treated in brief.

Semi-automatic component testers are in use today, as noted in a previous chapter. Therefore, the fundamentals of the system are known (Refs. 4b, 4c). Briefly, they consist of an impedance bridge with its oscillator supply, an amplifier and a phase discriminator acting as a null detector. The layout of the system

is shown in block diagram form in Figure 11. E_o is proportional to the bridge unbalance, and, if properly amplified, can be made to operate the reject circuit, if the unbalance is sufficient to indicate that the allowable tolerance limits on the component are not met. The heart of this system is the phase discriminator, shown in Figure 12, which operates as follows: The voltages to the rectifiers are $e + e_R$ and $e - e_R$. The rectified voltages across the load resistances are then proportional to the amplitudes of the two voltages. The d-c difference is E_o, and can be shown to be dependent on the amplitudes of the two voltages and the cosine of the angle between them, or what is essentially the unbalance signal.

In order to incorporate this into the automatic assembly line, one might choose one of two approaches. It is contemplated that there will be as many as thirteen component attaching machines in the production line, each handling a single size and single value component, with indexing being performed on the plate rather than the attaching heads. The components are contained in a hopper, from which they are removed, passed through testing clips and into a magazine where they lie until the attaching head picks them up. The first of the approaches mentioned above is to associate a single bridge tester with each of the attaching machines. It can then

be set for the desired tolerance of one particular component and needs no further adjustment. All the testers could be fed from the same oscillator supply, if desired. The second approach is a form of commutation, methods of which were discussed earlier in this chapter, which would switch appropriate ratio arms and standards into a single bridge in sequence with the switching from one machine to the next. No timing difficulties should occur, since it is planned that there shall be sufficient supply of extra components in each of the magazines to take care of the immediate needs of the production line. This extra supply is feasible, since the feed and testing mechanisms can operate during time when the attaching head is at rest.

3. Tester #3 - Circuit Tester

Tester #3 occurs at a stage in the fabrication where all the electronic components, except for vacuum tubes and tube shields, have been assembled and attached to the base plate. It is particularly advantageous to check the circuit at this stage, since the next process is the application of protective coating, after which faults cannot be repaired readily. The tester must ascertain that no physical damage has occurred to affect the circuit. The term physical damage encompasses such things as broken leads due to machine handling, altered component values due to heat of the soldering pro-

cess, poorly soldered joints, and unwanted leakage resistances produced by carbonization of solder flux by heat.

There are two general philosophies of circuit testing which might apply to this particular usage. Both of them, since the testing is to be accomplished automatically, will be based on the comparison between a standard, operative pilot circuit and the model fabricated by the automatic production line. The first is that of testing various combinations of components impedance-wise as they occur in the circuit. This has been done with some success in the past. (Refs. 1, 4e). The second is that of testing the performance of the assembly while in actual operation. These shall be referred to inthe following discussion as the circuit-tester type and the performance-tester type respectively.

a. Circuit-Tester Type

Since switching considerations were discussed earlier, they need not be reconsidered for the circuit tester, other than recognizing that some form of switching is necessary for accomplishing the testing of all the various component combinations which occur in the circuit. Circuit testing can be accomplished through the use of a differential amplifier, the basic circuit of which appears in Figure 13. The impedance elements of the pilot circuit and the test model are fed in series from an a-c supply, with the differential amplifier connected across the elements as shown. V_1 and V_2

are similar tubes which are so balanced that when the standard and test impedances are nearly equal, insufficient voltage to operate the reject mechanism will appear across the load resistance, since the control grids are fed in opposite phase. If they are unequal, however, which is the fault to be detected, an unbalance of feed to the tubes occurs and there is a net current resulting in the load, which can then be amplified to operate the reject mechanism and other control circuits.

The basic circuit produces adequate results for a-c testing. However, it requires the omission from the tests the resistors which are shunted by decoupling condensers, so some means for testing these must be provided. Figure 14 shows a circuit which can be used for both a-c and d-c tests. It centers around two triode-hexode tubes, although later single-tube envelopes can be used for the same purpose. In the a-c position, the circuit operates as in Figure 13. In the d-c position of the switches, the a-c supply is switched to the triode sections, which are connected internally to the mixer grids of the hexode sections. R_1, R_2, Z_s and Z_t form a bridge with R_D connected across the opposite corners from the power supply. The hexode control grids receive the signal from the ends of R_D and form an out-of-balance detector. When the bridge is balanced, the grids will be at equal potentials and the alternating voltage in the plate

circuit will be very small, since the a-c signals to the mixer grids are equal and opposite in phase. When the bridge is unbalanced, however, the control grids will no longer be at equal potentials, which condition will allow the alternating voltage in the plate circuit to be sufficient to energize the reject mechanism.

As an alternative to the a-c impedance comparison, one might consider the comparison of decay times of RC combinations between the standard circuit and the test circuit. This might be accomplished by applying a step voltage to the circuit in place of the a-c testing voltage. Then, with an appropriate delay between the voltage application and the measurement of the outputs, the amounts by which the two circuits have decayed are compared. If they are not within reasonable tolerance limits, the piece is then rejected.

This method would, in general, be inferior to the a-c impedance comparison method. This follows from consideration of the various combinations of components possible. Whereas the methods mentioned above are not dependent upon the voltage across a particular component, but of the impedance seen looking into the entire combination, this method requires that the combinations must be accessible at all points of junction, in order to obtain a buildup or decay of voltage.

Figure 15 is a block diagram of the a-c, d-c circuit-tester type system. The concept of the mechanical configuration is for a

head to contain testing probes which would fit into the tube sockets, and auxiliary probes to fit into any other external contact rivets which are accessible. It is not advisable to attempt to place probes on any of the individual components, due to the manner in which they are attached to the base plate. Pressure on those leads could cause physical damage to the assembly.

It should be stressed that, due to the limited access to contacts, each component or conductor can not be checked individually. It is entirely possible that particular components could be masked from the test, where they might be connected to components of a much higher value. The main concern, then, is to insure that all components are present and that connections are electrically sound.

b. Performance-tester type.

The limitations mentioned in the preceding paragraph lead to the suggestion of the second type of test. While not reaching the inaccessible components, nor even, for that matter, the impedance combinations tested above, it accomplishes the end result with circuitry less complex and with no need for switching from one circuit section to another. Since the entire circuit is assembled, except for tubes, when it reaches this stage of production, it is feasible that a performance test might be performed. Any deviation

of components from their supposed values, or errors derived from processing, would result in the failure of the circuit to meet the design specifications. In a comparison test against a pilot circuit, this would result in an output voltage which would operate the reject mechanism. Figure 16 is a block diagram of this system.

The testing head, in this case, would contain representative tubes of the type used in the assembly. When the head is lowered into position, supply voltages, input signals and output voltages are fed and received through the contacts intended ultimately for that purpose. This simulates actual operation of the finished assembly. When the head is raised, the heaters of the tubes contained in the head would be maintained at operating temperature by an auxiliary supply, in order that the tester is ready for testing immediately after connections are made by lowering the head.

The comparison circuit used in this case could be the same as for the circuit-tester type, except that a 180° phase-shifting network for one of the circuit output voltages is necessary to bring about the out-of-phase feeding of the differential amplifier.

If it is desired to add error-indicating features to this system, then the system becomes more complex, while not detracting

from the principle of the test. This added requirement could be met by designing the tester to make consecutive measurements of pertinent potentials throughout the system, as it was operating normally. On a differential comparison basis, it would be immaterial whether there were an input signal applied or not. The error indication follows from the necessary switching to accomplish the various measurements. As long as a particular sub-circuit is associated with a certain spot in the overall sequence of switching, then a fault-location can be made and a signal generated to operate a recording device.

Essentially, this tester would incorporate measurements of the following types: (1) high d-c voltages such as are found on plates and screens; (2) low d-c voltages such as are found on cathodes and other bias circuits; and (3) a-c voltages for heater power requirements. With the comparison features, tolerance measurements are implied.

Note should be made here of the possible difficulty in achieving an adequate input signal for other circuits being fabricated. If the assembly, for instance, were to be an audio amplifier, the input signal should be an audio sweep-frequency generator, with constant input output impedance over the frequency range. It is beyond the scope of this paper, however, to list the various possible types of equipment and to devise means for generating input signals for each. This is a matter for specific design as the occasion arises.

4. Tester #4 - Performance

This tester would differ from the one described in the preceding paragraphs only in that the tubes used are the ones which will remain in the assembly when it leaves the line. For this reason, somewhat longer time for the test will be required, in order that the heaters might reach operating temperature. In all other respects, the same procedures are followed.

This completes the means for achieving the required testing. The utilization of one or all the testers depends on the economic evaluation of those involved in automatic, mechanized production. When the decision is made as to which tester or testers are necessary to the line, then, based upon the principles set forth in this paper, specific applied designs can be accomplished for the necessary quality control of the mechanized production line.

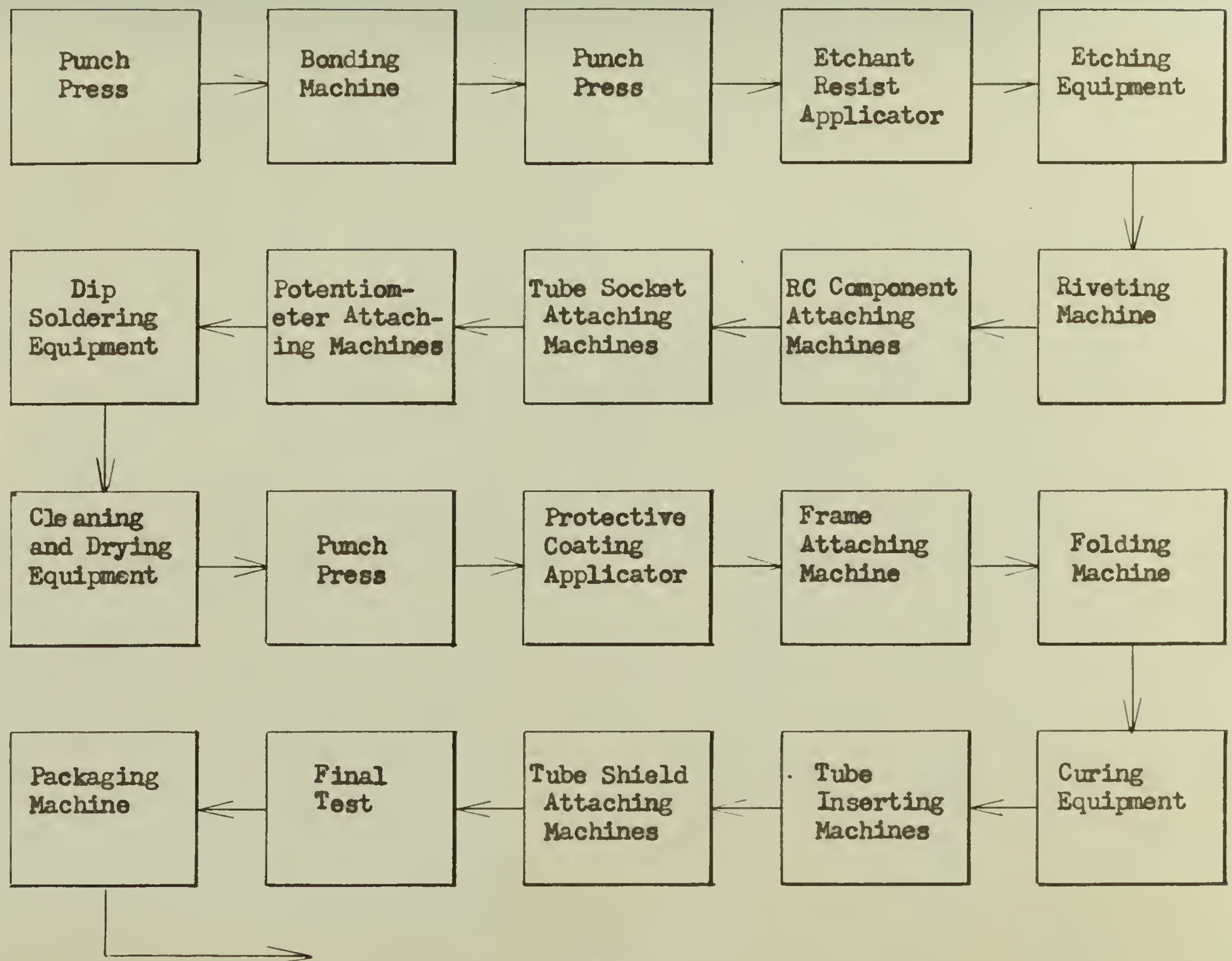


Figure 1. Block of Assembly Line

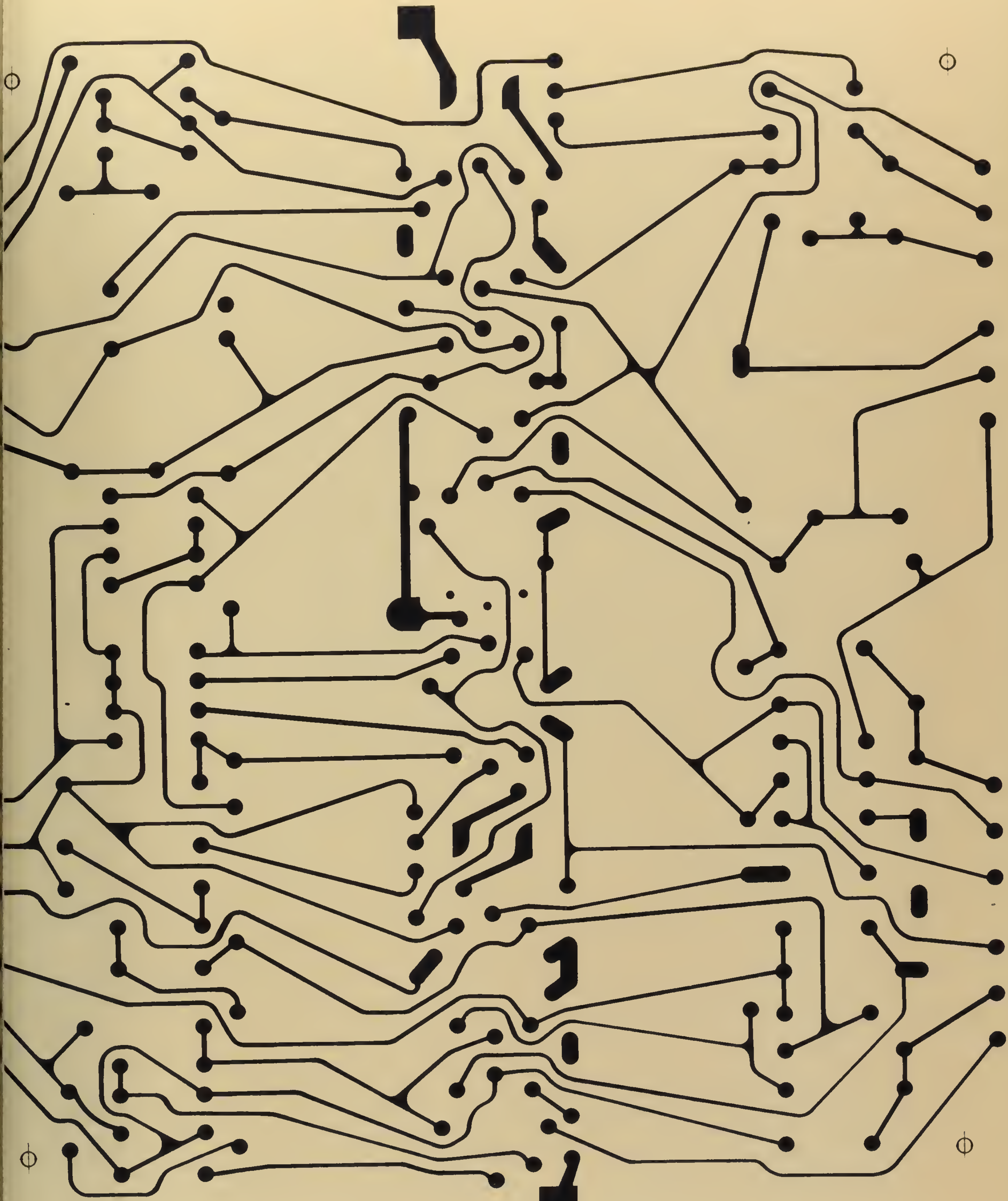


Figure 2. Conductor Pattern

Figure 3. Mechanical Block

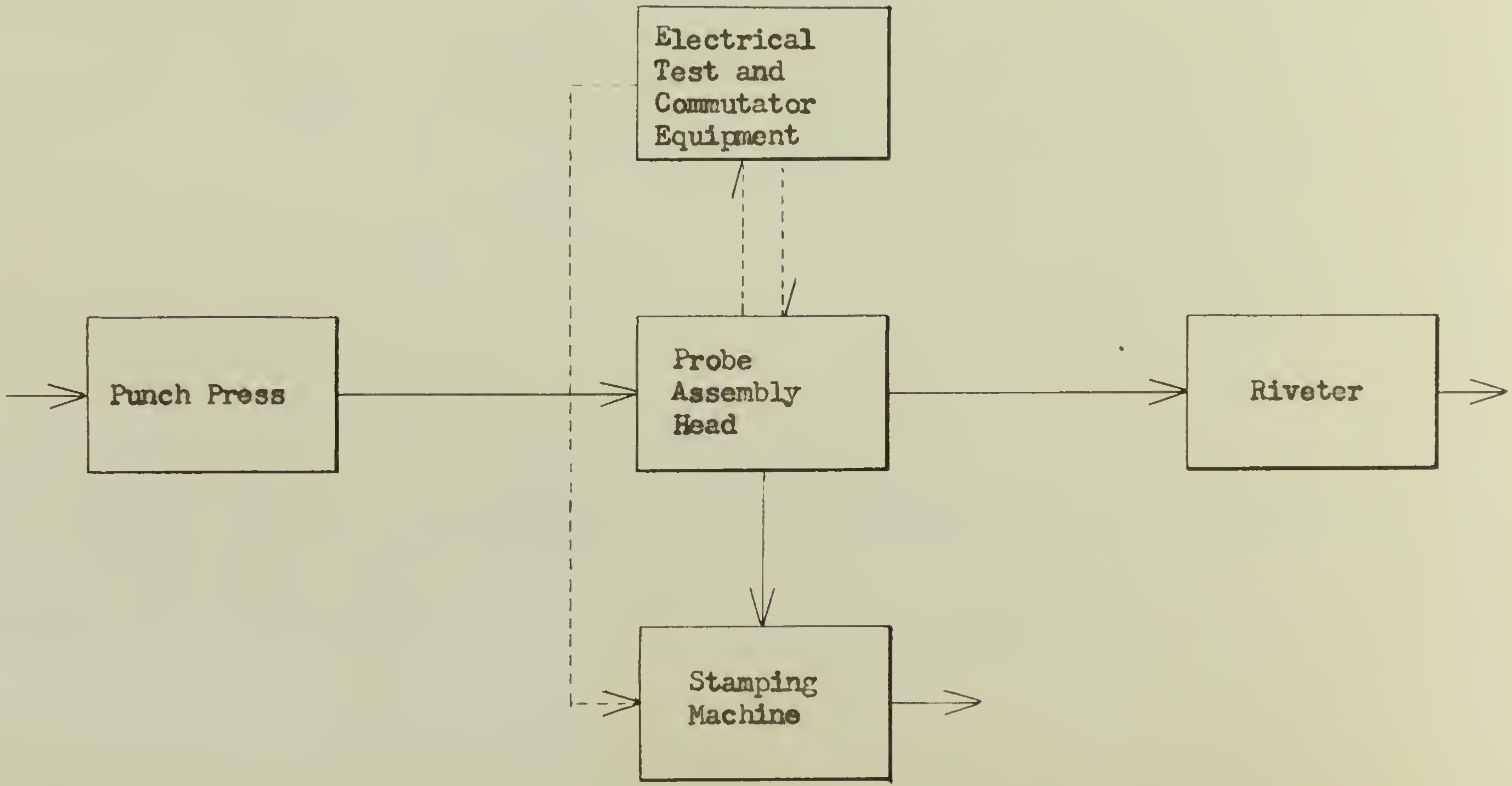
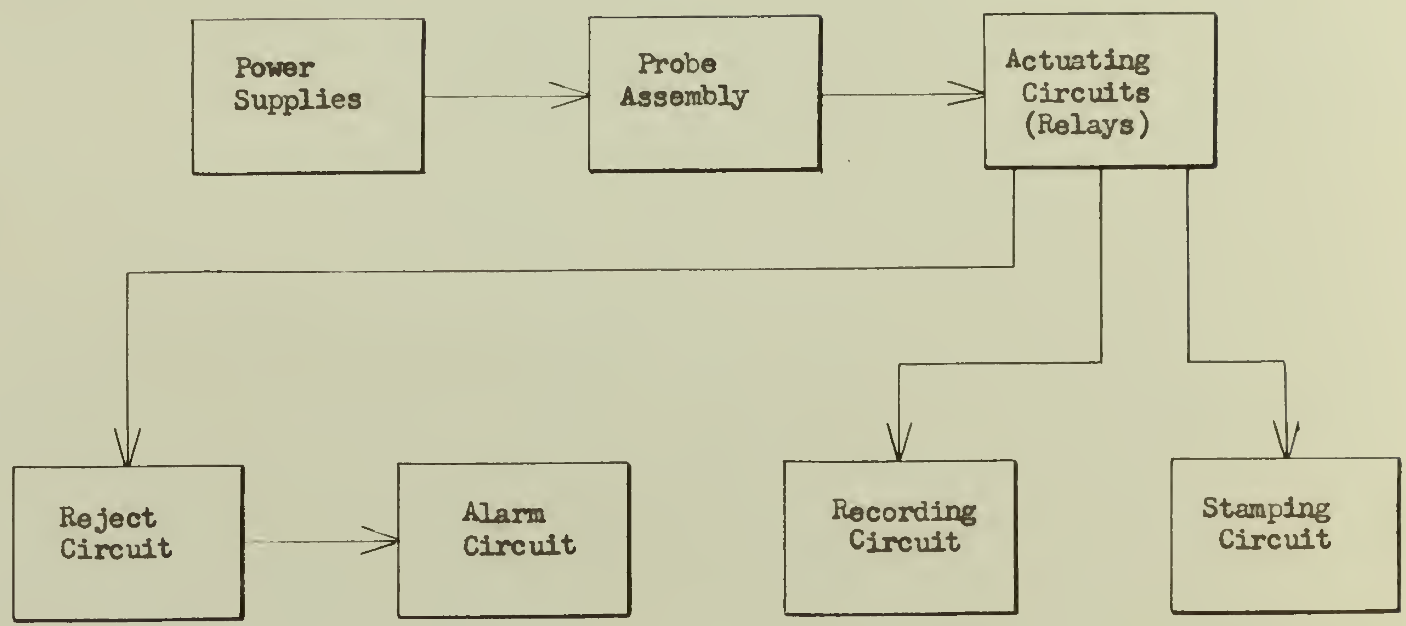


Figure 4. Electrical Block



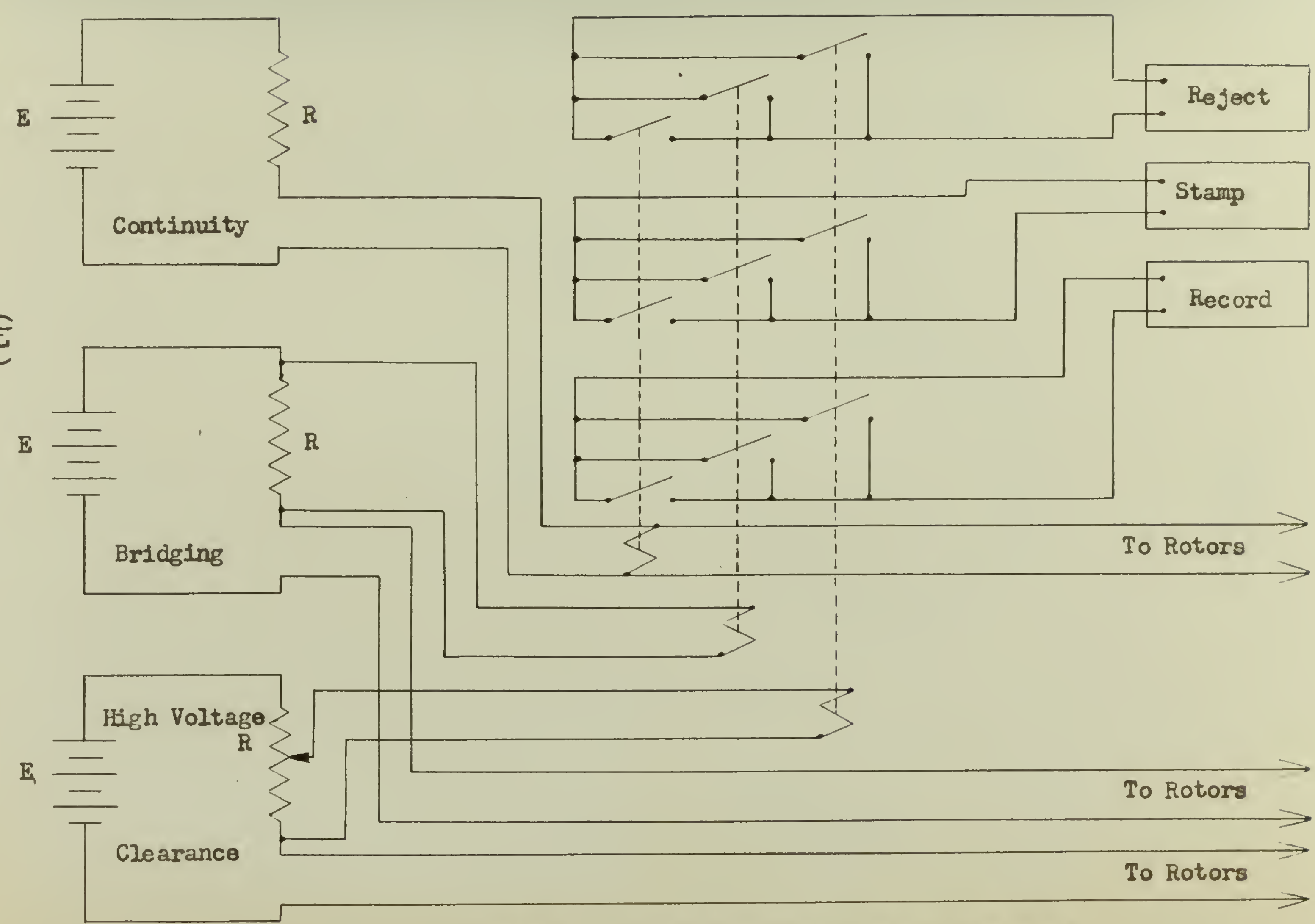


Figure 5. Basic Electrical Theory, Tester #1.

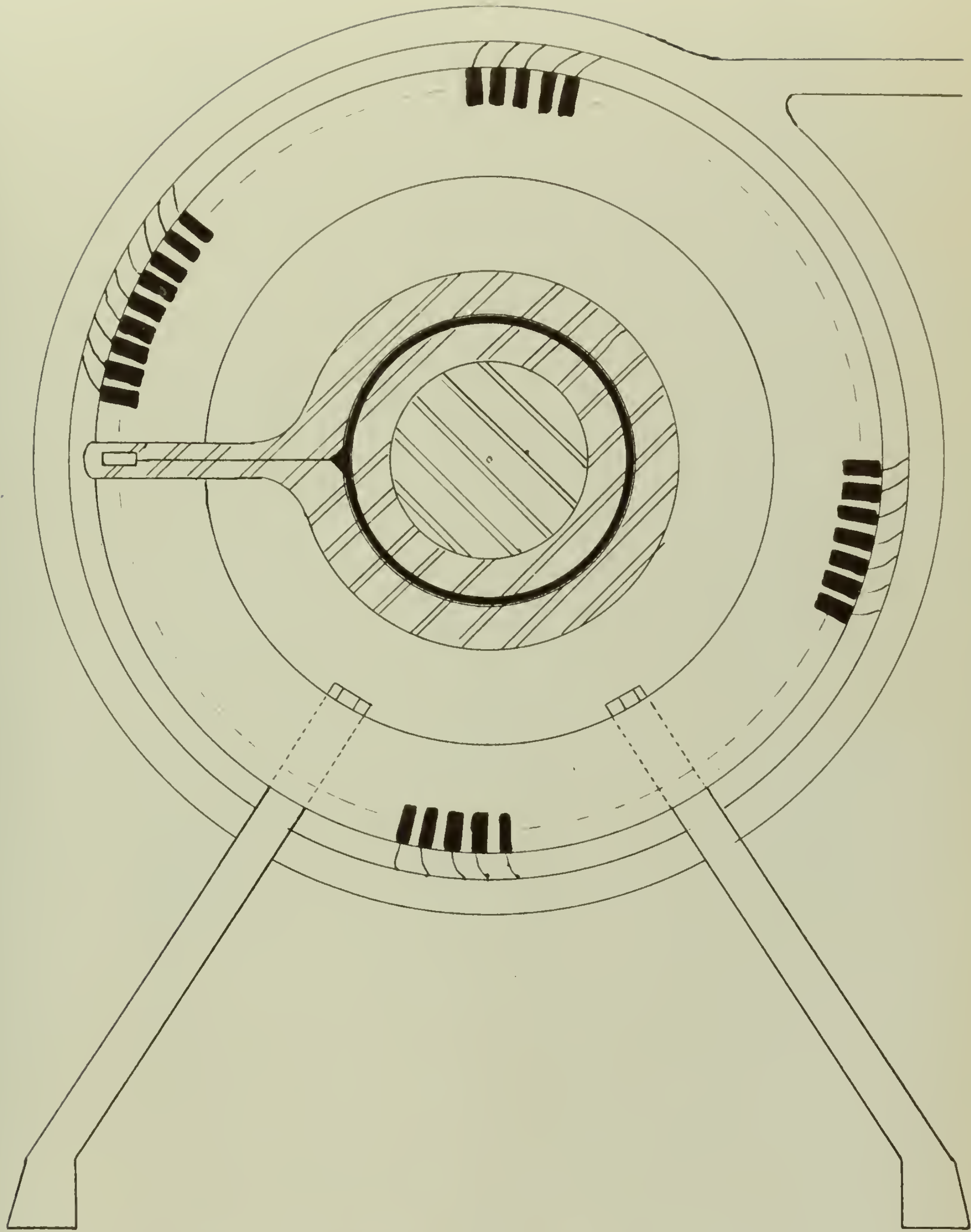


FIGURE 6. COMMUTATOR (Side View)

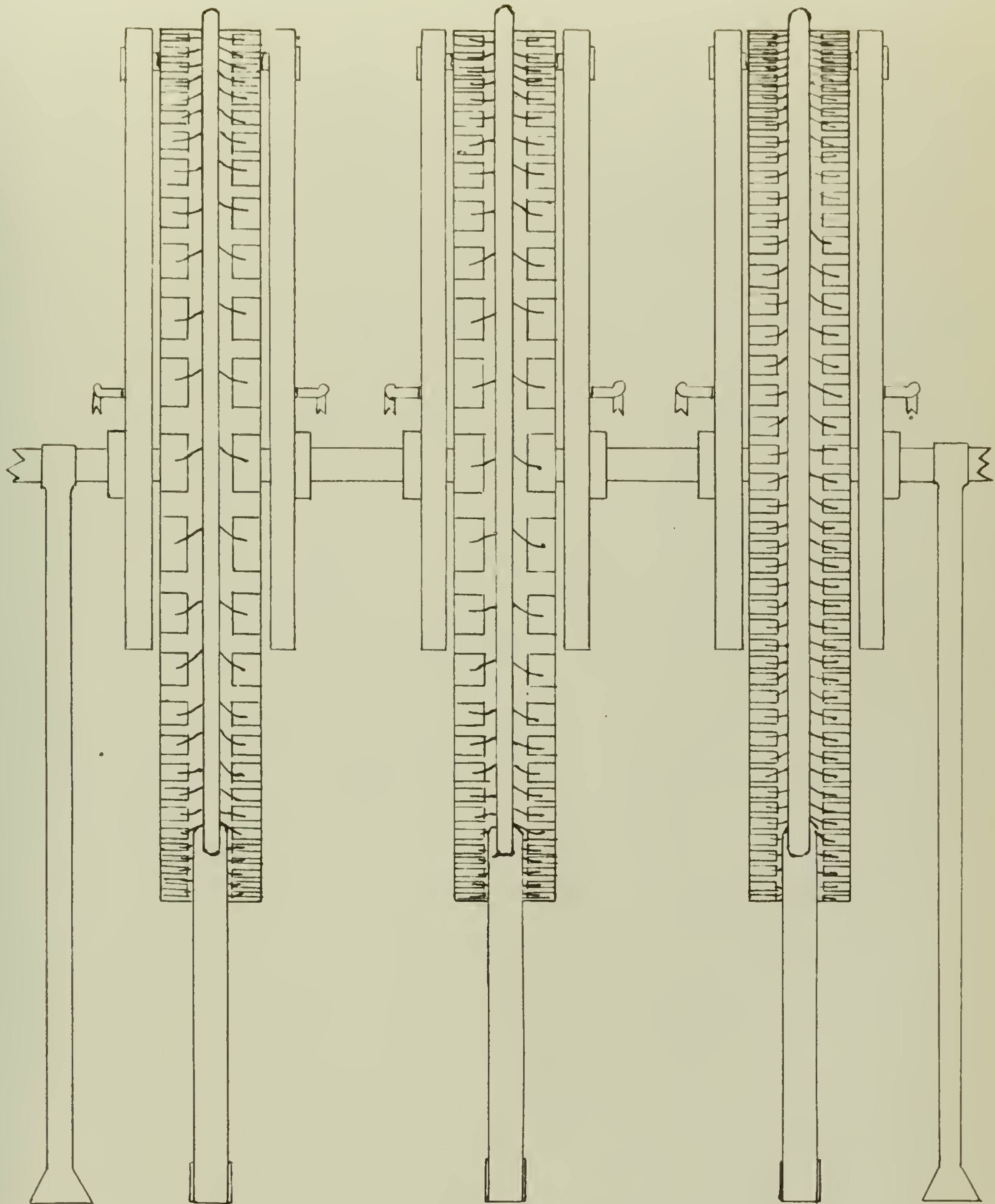


Figure 7. Commutator (Front View)

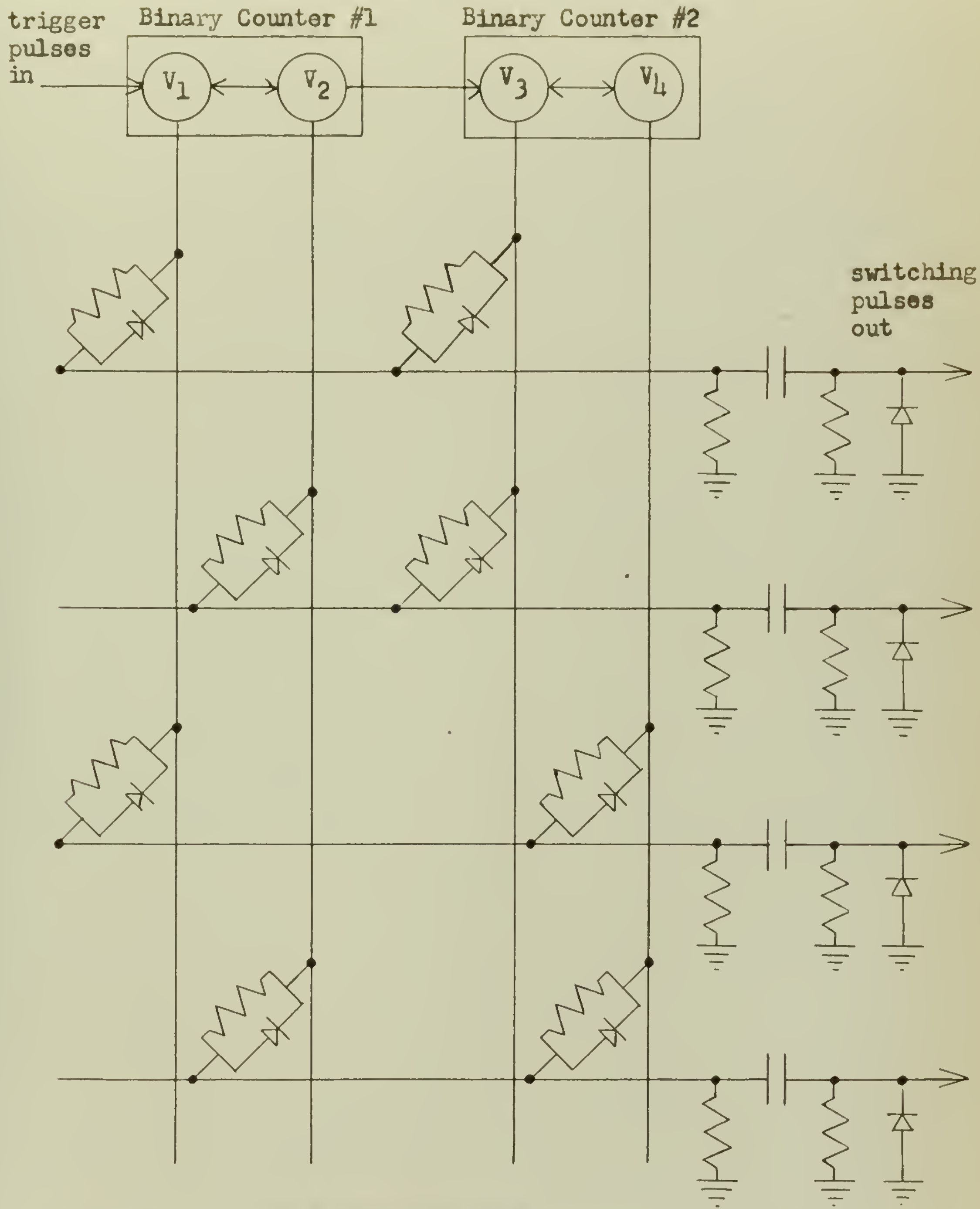
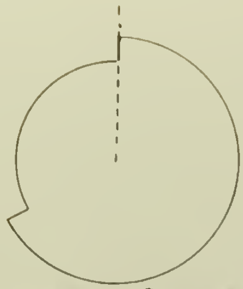
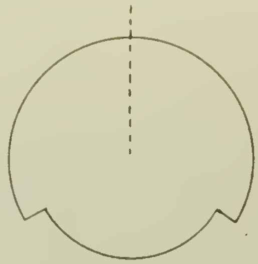


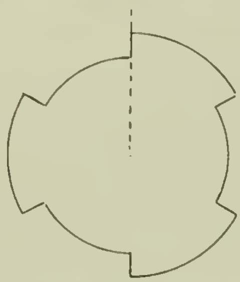
FIGURE 8. DIODE RESISTANCE MATRIX.



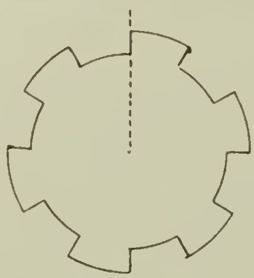
#1- 240° Make, 0° Phase



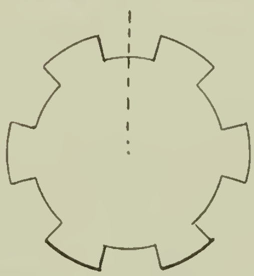
#2- 240° Make, 120° Phase



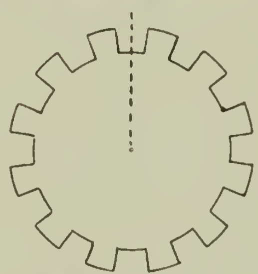
#3- 60° Make, 0° Phase



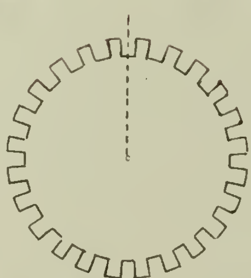
#4- 30° Make, 0° Phase



#5- 30° Make, -15° Phase



#6- 15° Make, -7.5° Phase



#7- 7.5° Make, -3.75° Phase

FIGURE 9. CAM AMPLITUDE AND PHASING.

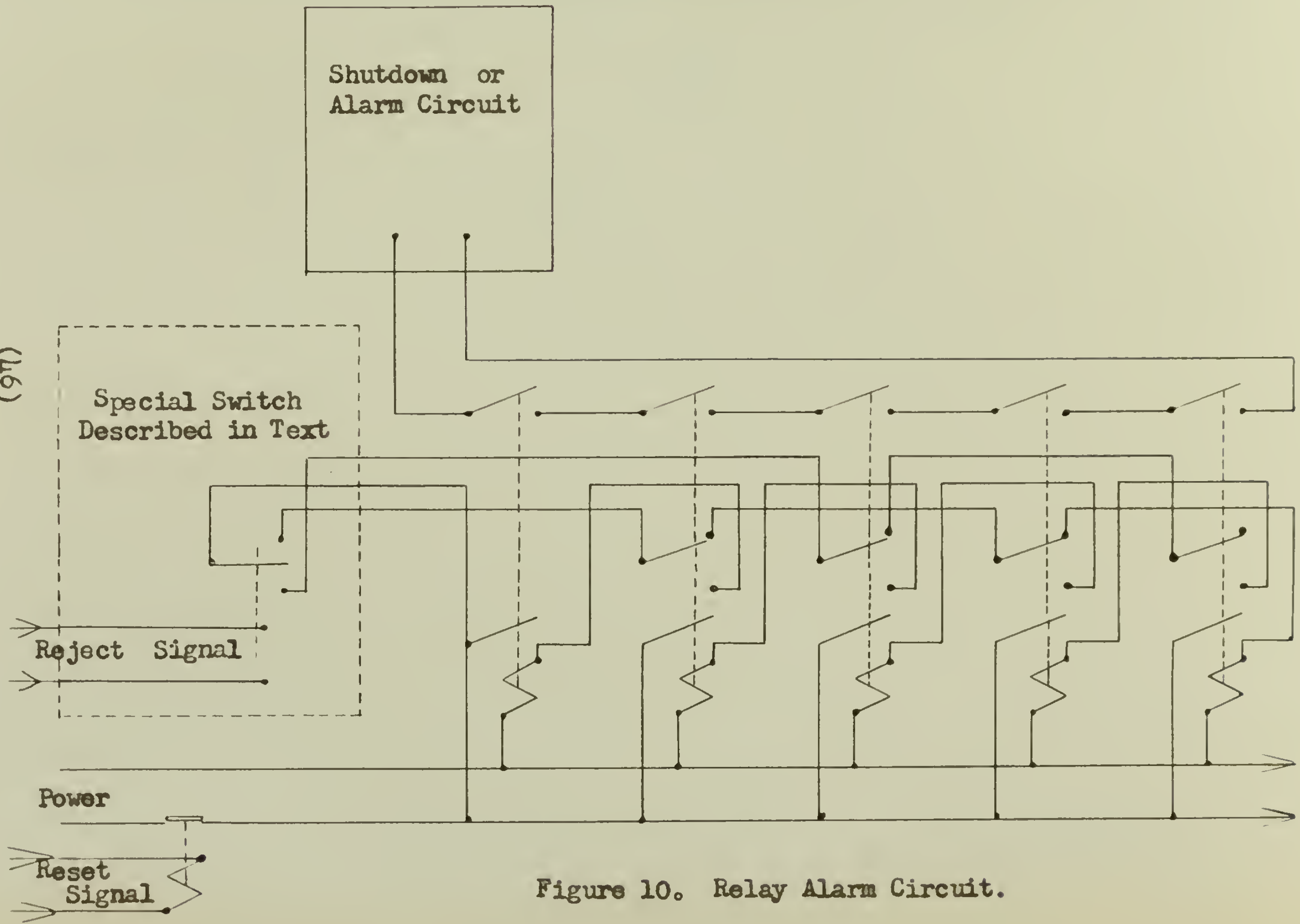


Figure 10. Relay Alarm Circuit.

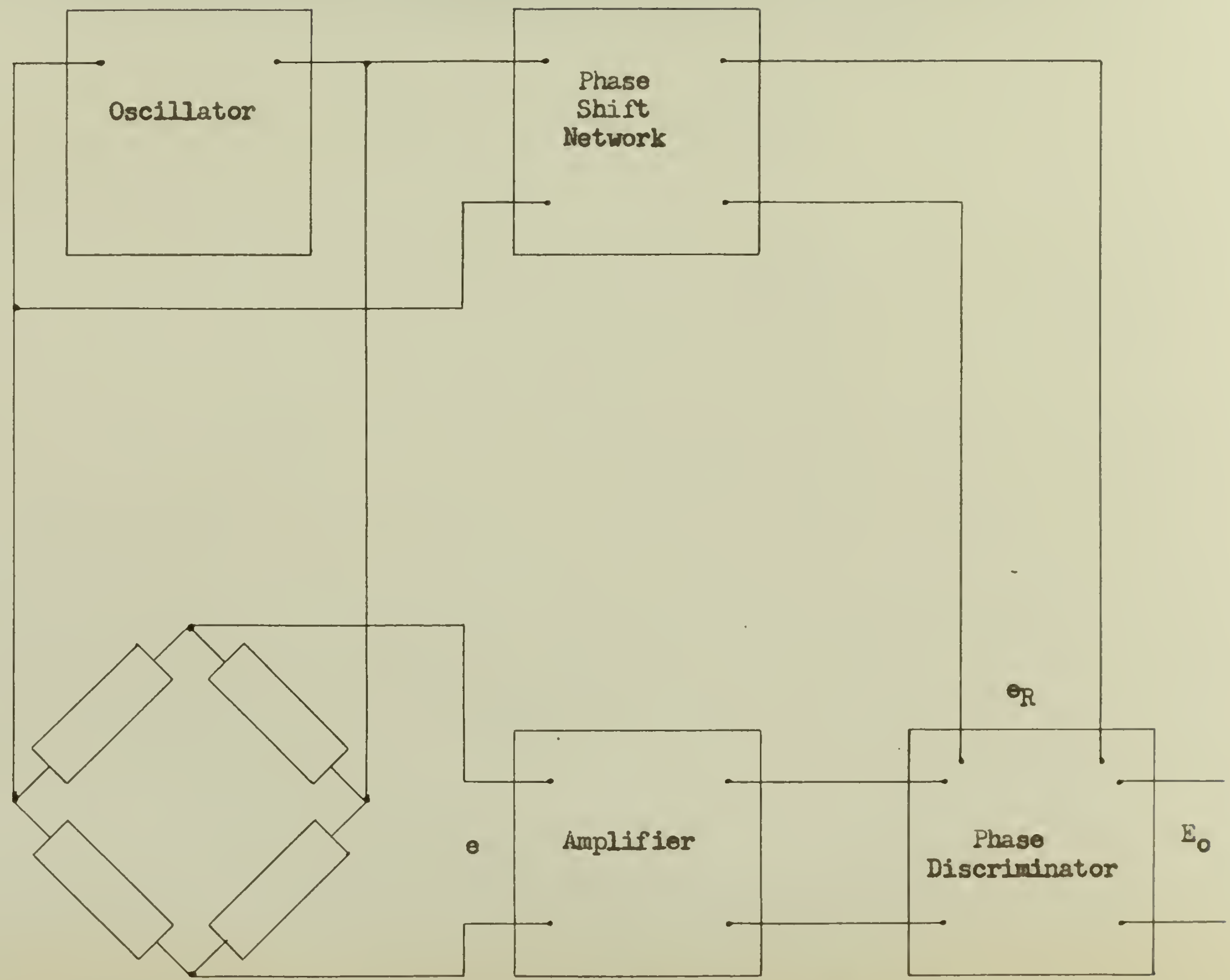
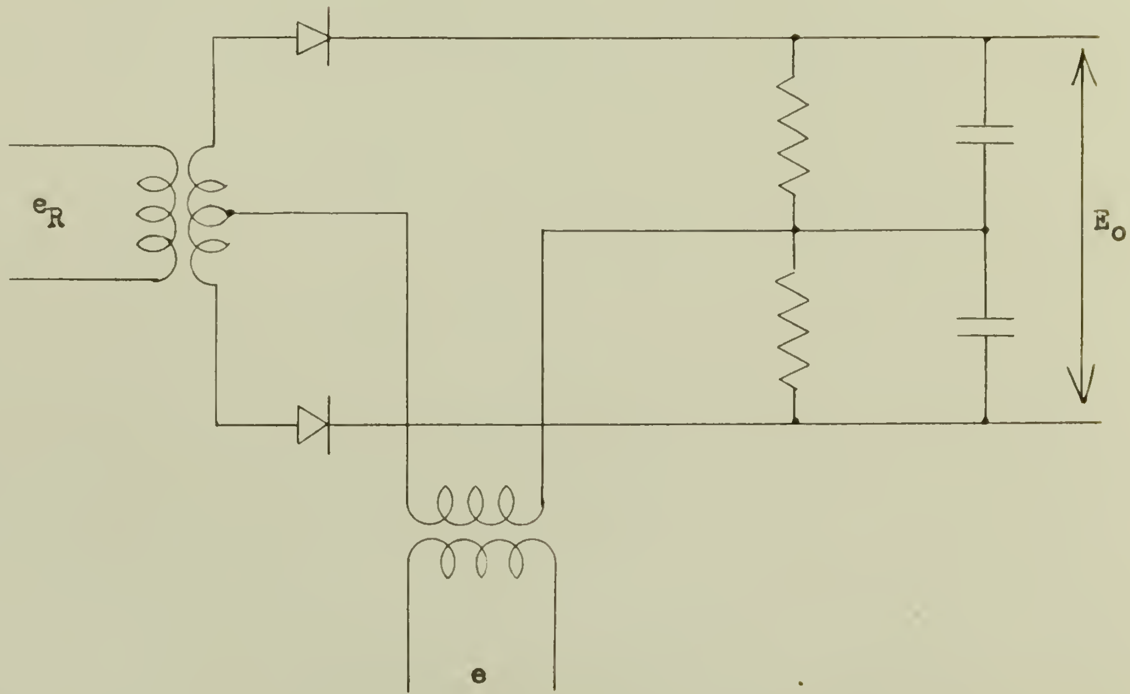


Figure 11. Component Bridge Block

Figure 12. Phase Discriminator



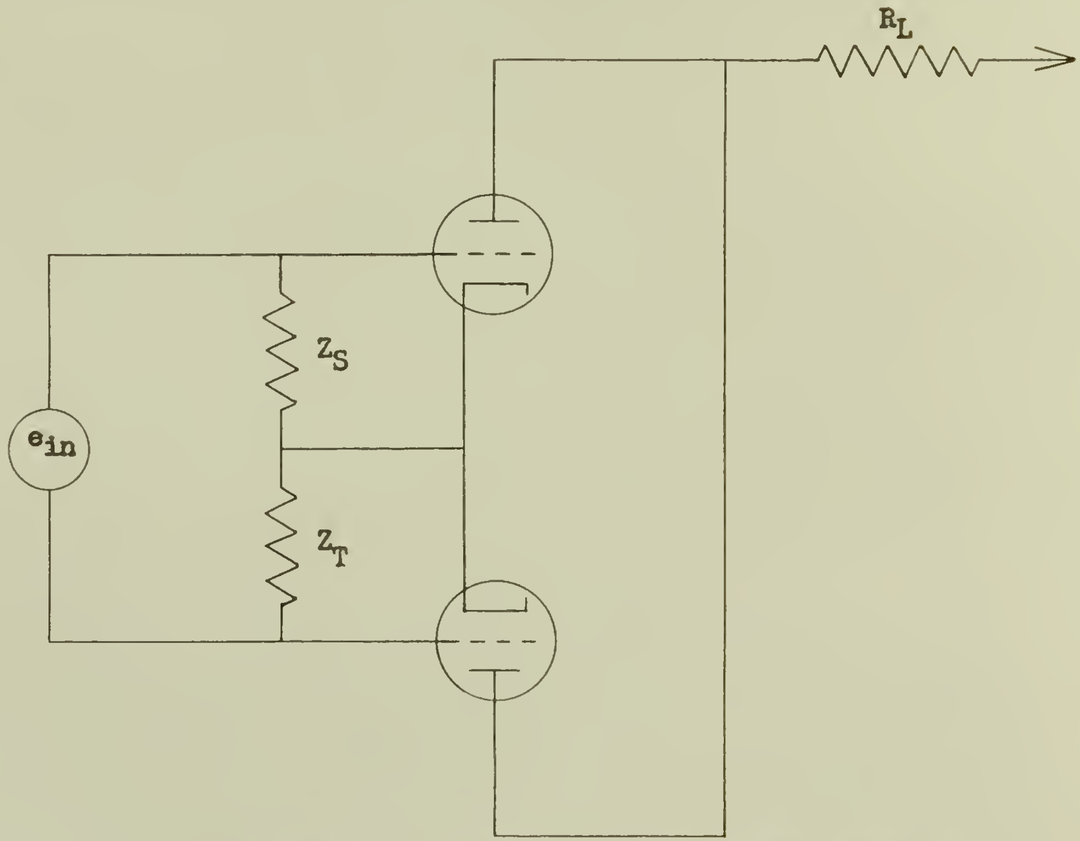


Figure 13. Basic Differential Amplifier

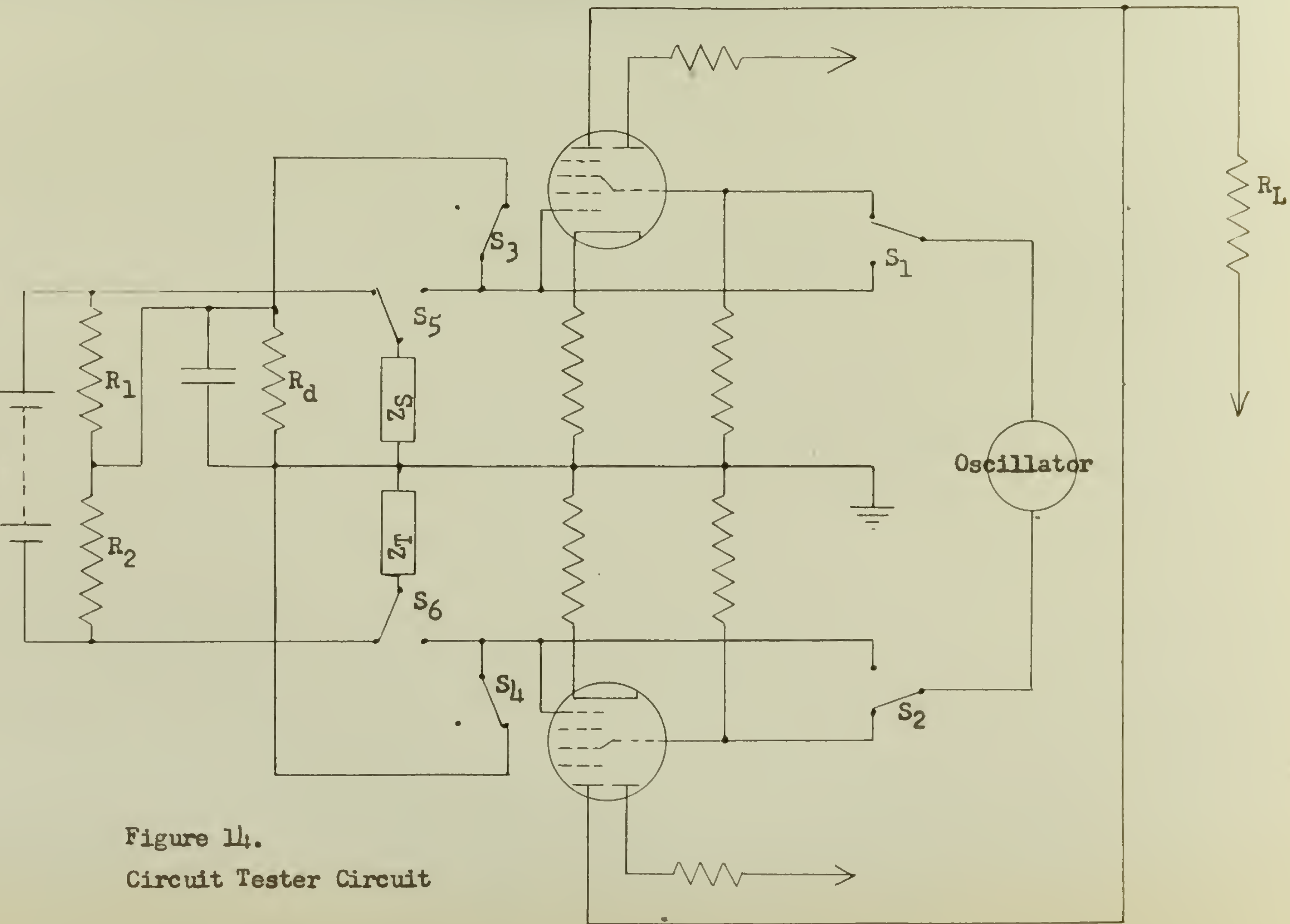


Figure 14.
Circuit Tester Circuit

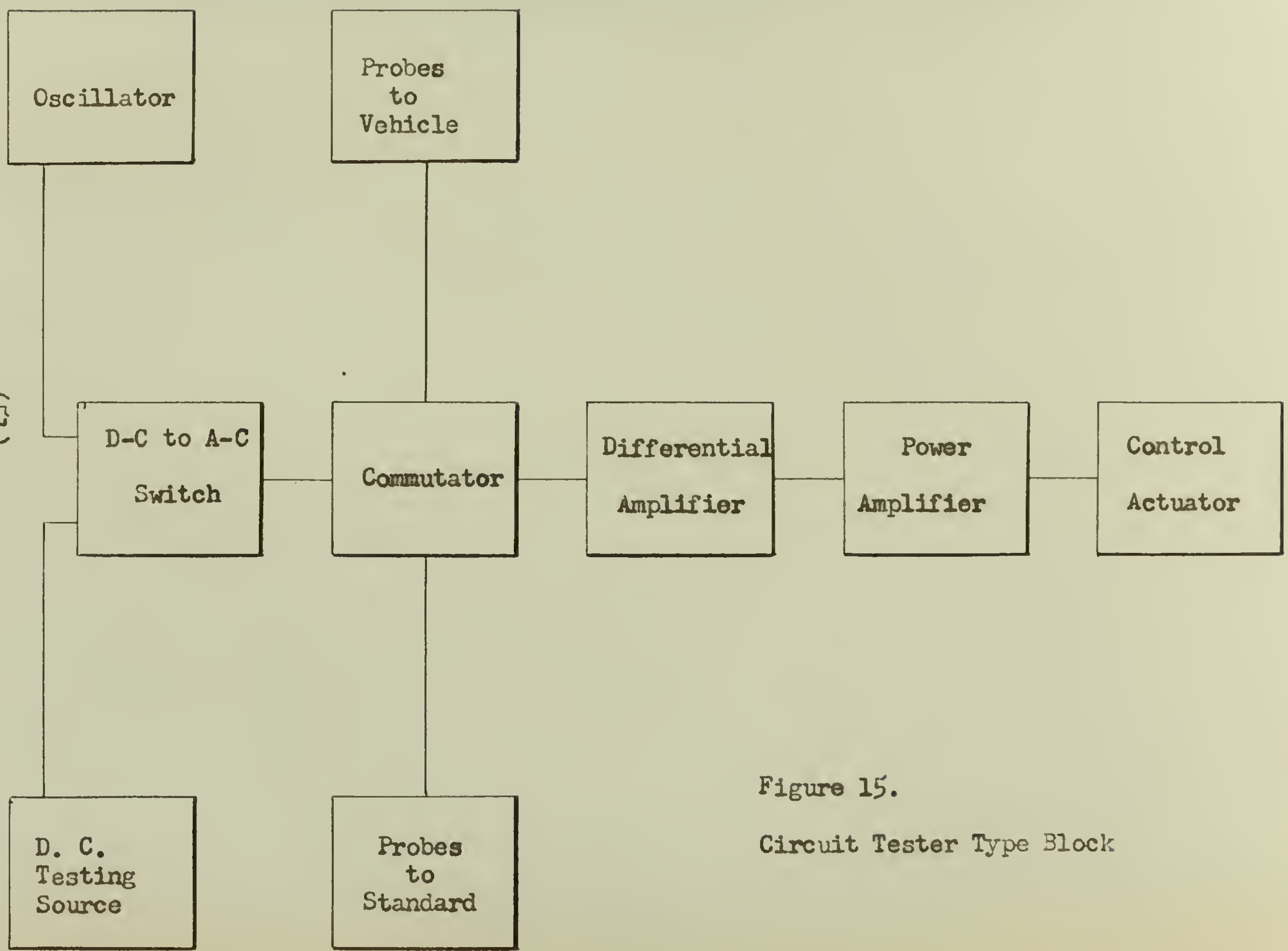


Figure 15.

Circuit Tester Type Block

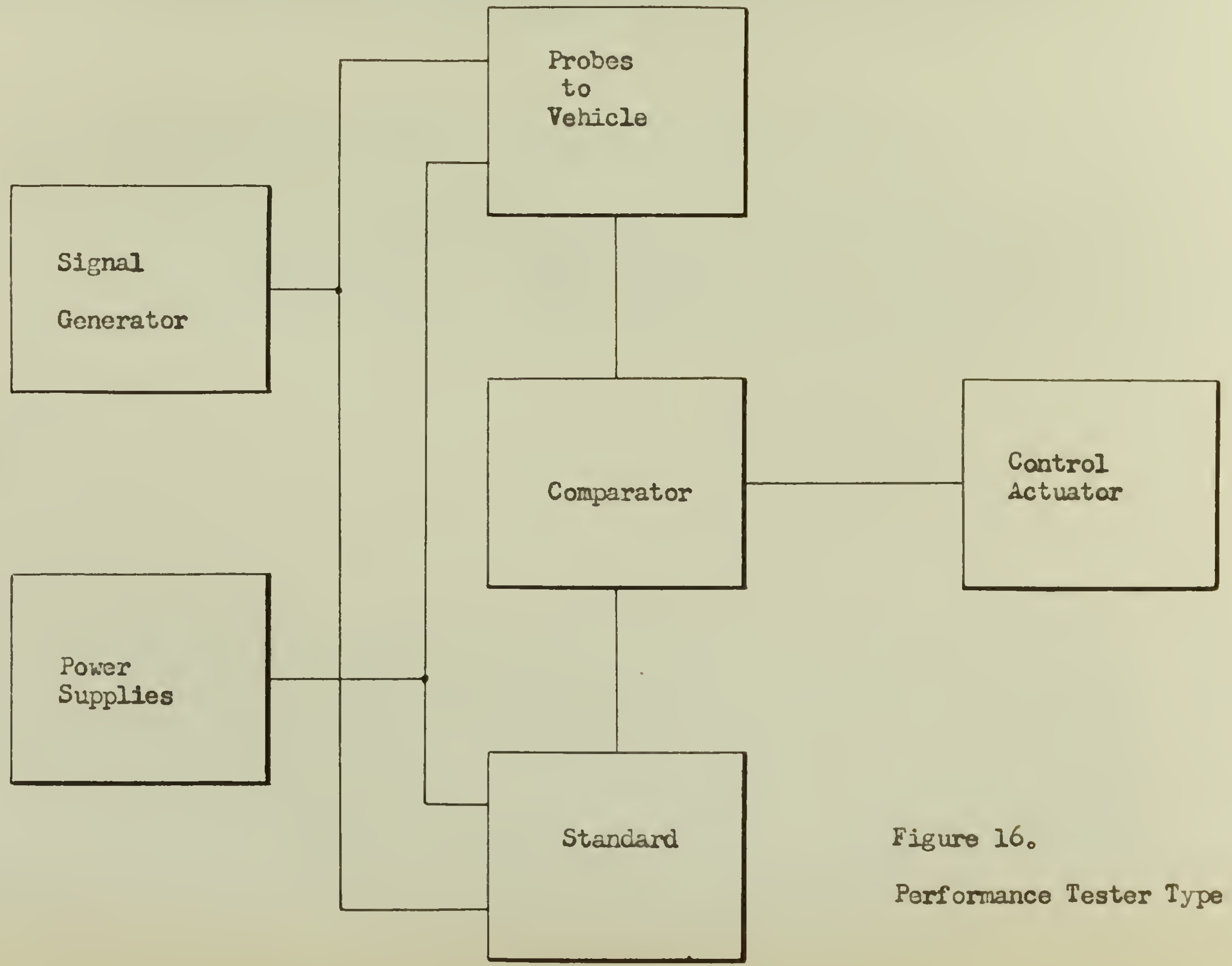


Figure 16.

Performance Tester Type Block.

1	●	●	●	●			
2	●	●	●	●			●
3	●	●	●	●		●	●
4	●	●	●	●		●	
5	●	●	●	●	●	●	
6	●	●	●	●	●	●	●
7	●	●	●	●	●		●
8	●	●	●	●	●		
9	●	●	●		●		
10	●	●	●		●		●
11	●	●	●		●	●	●
12	●	●	●		●	●	
13	●	●	●			●	
14	●	●	●			●	●
15	●	●	●				●
16	●	●	●				
17	●	●		●			
18	●	●		●			●
19	●	●		●		●	●
20	●	●		●		●	
21	●	●		●	●	●	
22	●	●		●	●	●	●
23	●	●		●	●		●
24	●	●		●	●		
25	●	●			●		
26	●	●			●		●
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29	●	●				●	
30	●	●				●	●
31	●	●					●
32	●	●					
33	●		●	●			
34	●		●	●			●
35	●		●	●		●	●
36	●		●	●		●	
37	●		●	●	●	●	
38	●		●	●	●	●	●
39	●		●	●	●		●
40	●		●	●	●		
41	●		●		●		
42	●		●		●		●
43	●		●		●	●	●
44	●		●		●	●	
45	●		●			●	
46	●		●			●	●
47	●		●				●
48	●		●				

49	●			●			
50	●			●			●
51	●			●		●	●
52	●			●		●	
53	●			●	●	●	
54	●			●	●	●	●
55	●			●	●		●
56	●			●	●		
57	●				●		
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59	●				●	●	●
60	●				●	●	
61	●					●	
62	●					●	●
63	●						●
64	●						
65		●	●	●			
66		●	●	●			●
67		●	●	●		●	●
68		●	●	●		●	
69		●	●	●	●	●	
70		●	●	●	●	●	●
71		●	●	●	●		●
72		●	●	●	●		
73		●	●		●		
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75		●	●		●	●	●
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77		●	●			●	
78		●	●			●	●
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81		●		●			
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TABLE I. BINARY CODE

BIBLIOGRAPHY

1. Williams, R.C.G. et.al. The Design of a Universal Automatic Circuit Tester, and Its Application to Mass Production Testing. Journal of the Institution of Electrical Engineers, Vol. 94, Part 3, January 1947.

2. Wolfson, H. M. An Overall Inspection Program. Electrical Engineering, Vol. 68, July 1949. (Pub. AIEE)

3. Electronics Engineering (London)
   a. Vol. 20 #250, December 1948.
   b. Baker, G. T. A Method for the Measurement of Capacitance and Resistance. Vol. 22 #269, July 1950.
   c. Silberstein, J. M. Automatic Circuit Checker for Television Receivers. Vol. 23 #280, June 1951.

4. Electronics (McGraw -Hill)
   a. Campbell, R. D. and Totah, E. J. Automatic Limit Bridge for Component Testing. Vol. 21 #1, January 1948.
   b. Daubendick, A. W. High Speed Resistor Tester. Vol 21, #2, February 1948.
   c. Fahnestock, J. D. Automatic Bridge for Component Testing. Vol. 22 #4, April 1949.
   d. Graham, J. F. Automatic A-C Bridges. Vol. 24 #2, February 1951.
   e. Automatic Testing of Military Radio Sets. Production Techniques Section, Vol. 25 #6, June 1952.

5. Tele-Tech (Caldwell-Clements) Vol. 9 #9, September 1950.

6. Wireless World (Iliffe & Sons, Ltd., London) Vol. 56 #1, January 1950.

7. Fortune (Time, Inc.) August 1948.

8. Packard, C. A. Relay Engineering (Struthers-Dunn, 1945)

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Automatic electrical testing in mechanized production lines